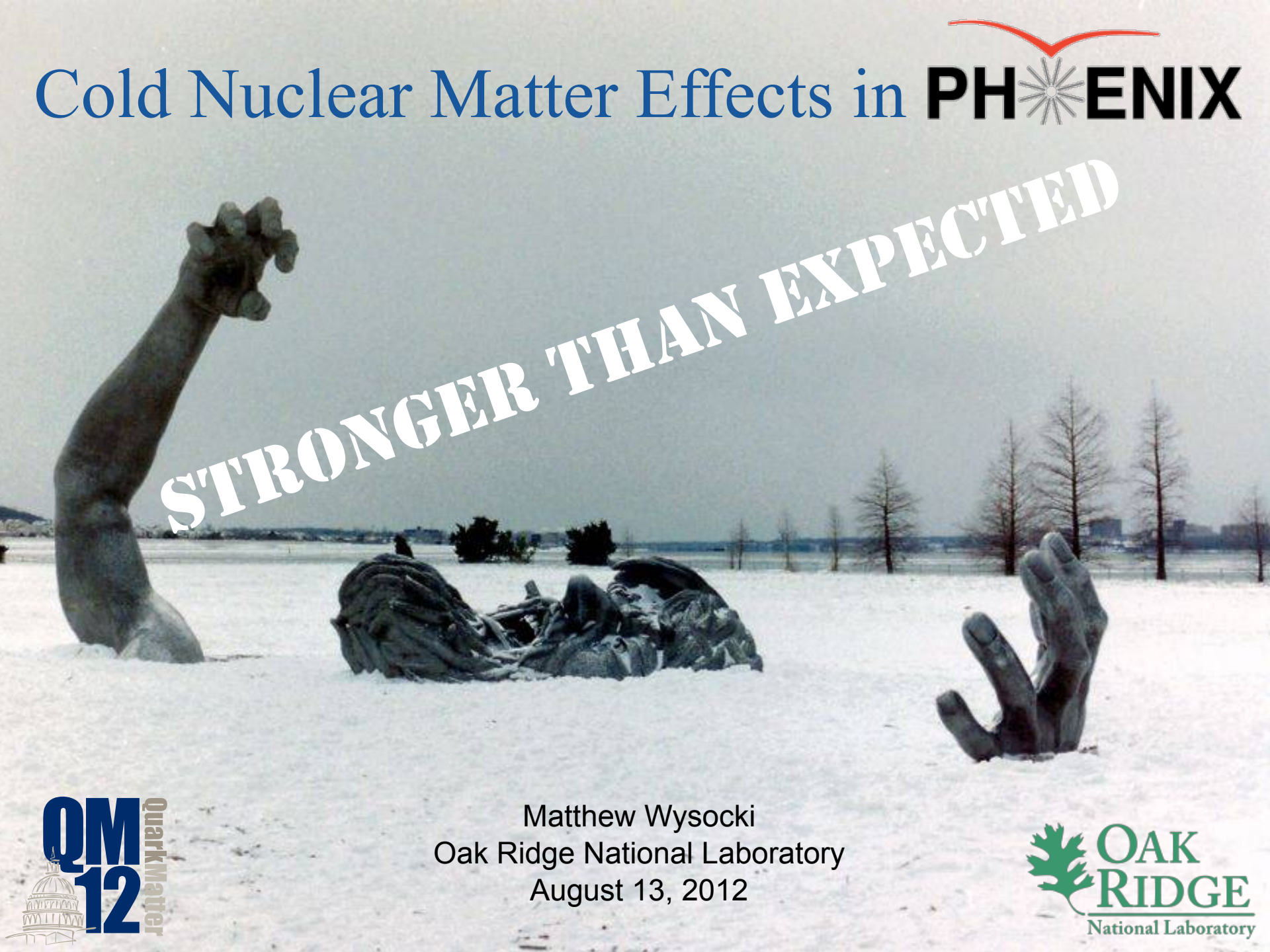
Cold Nuclear Matter Effects in PHENIX



Matthew Wysocki
Oak Ridge National Laboratory
August 13, 2012

QM12 Quark Matter

OAK RIDGE National Laboratory

Introduction

d+Au collisions at RHIC allow us to measure cold nuclear matter (CNM) effects without additional effects from a hot medium.

PHENIX recorded *d*+Au collisions in 2003 and higher statistics in 2008.

The effects we're interested in measuring include:

1. Shadowing of parton distributions
2. Cronin enhancement at moderate p_T
3. Nuclear break-up of heavy quarkonia
4. And possibly more…

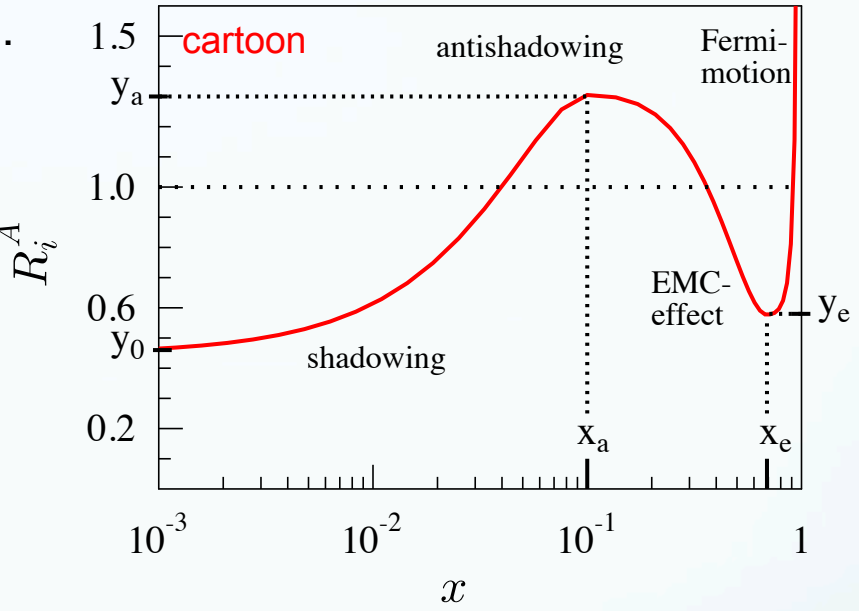
Nuclear Shadowing

Parton distribution functions in nuclei deviate from those in nucleons.

Enhancement/suppression varies with x, Q^2.

$$R_i^A(x,Q^2) = \frac{f_i^A(x,Q^2)}{A\, f_i^{\text{nucleon}}(x,Q^2)}, \quad f_i = q, \bar{q}, g,$$

Possibly gluon saturation/CGC effects at very low x, not crystal clear from the data-theory comparisons.



Nuclear PDFs are available that incorporate shadowing effects. EPS09 is one example, as well as EKS98, nDSg, and others.

- EPS09 provides multiple variations of the PDFs so that an uncertainty band can be calculated.
- EPS09s recently released with *b*-dependence, see arxiv:1205.5359

Cronin Enhancement

PHYSICAL REVIEW D VOLUME 11, NUMBER 11 1 JUNE 1975

Production of hadrons at large transverse momentum at 200, 300, and 400 GeV *

J. W. Cronin, H. J. Frisch, and M. J. Shochet
The Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637

J. P. Boymond, P. A. Piroué, and R. L. Sumner
Department of Physics, Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540

(Received 5 December 1974)

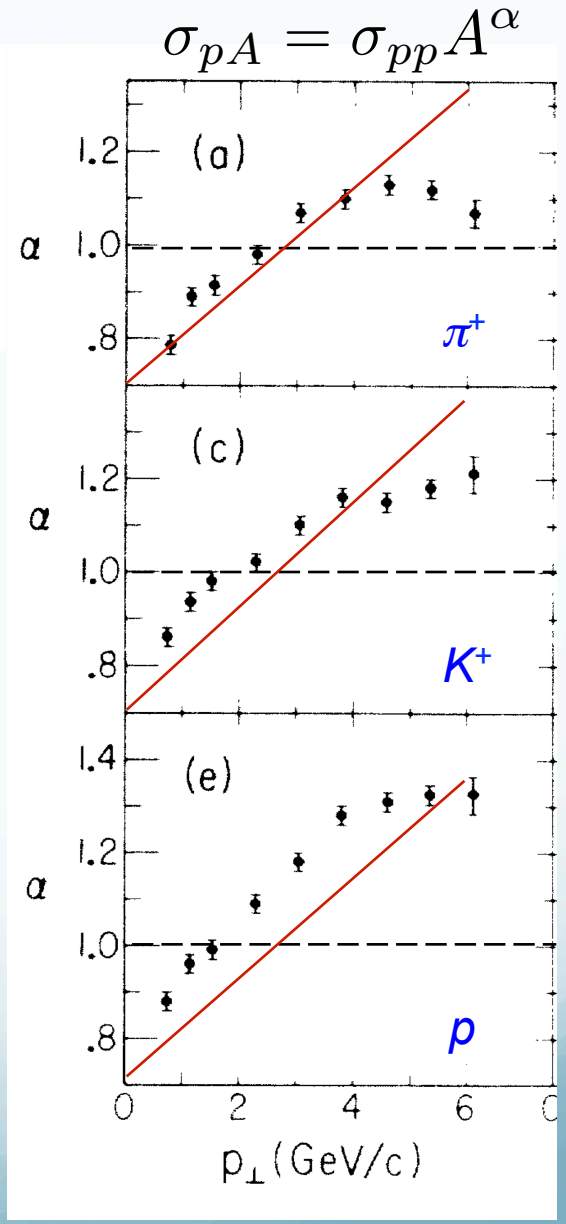
Enhancement of hadron production in heavy ion collisions

Usually modeled as multiple scattering of the incoming parton on the nucleus.

Most models don't have any PID dependence…

- However, measured enhancement is larger for protons than pions/kaons.
- Originally thought to be due to steeper p_T spectrum of protons and that it would go away at higher energies.

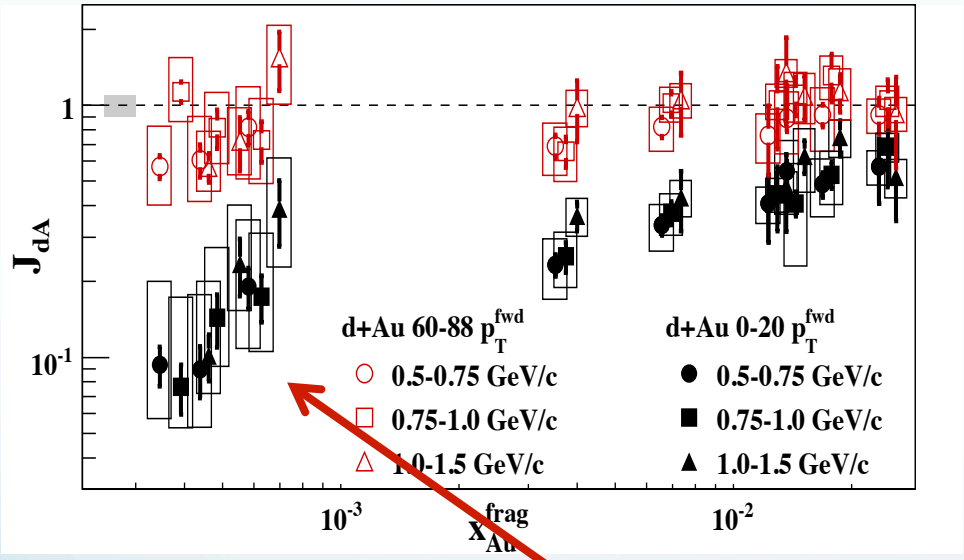
But proton enhancement is still much larger at RHIC energies!



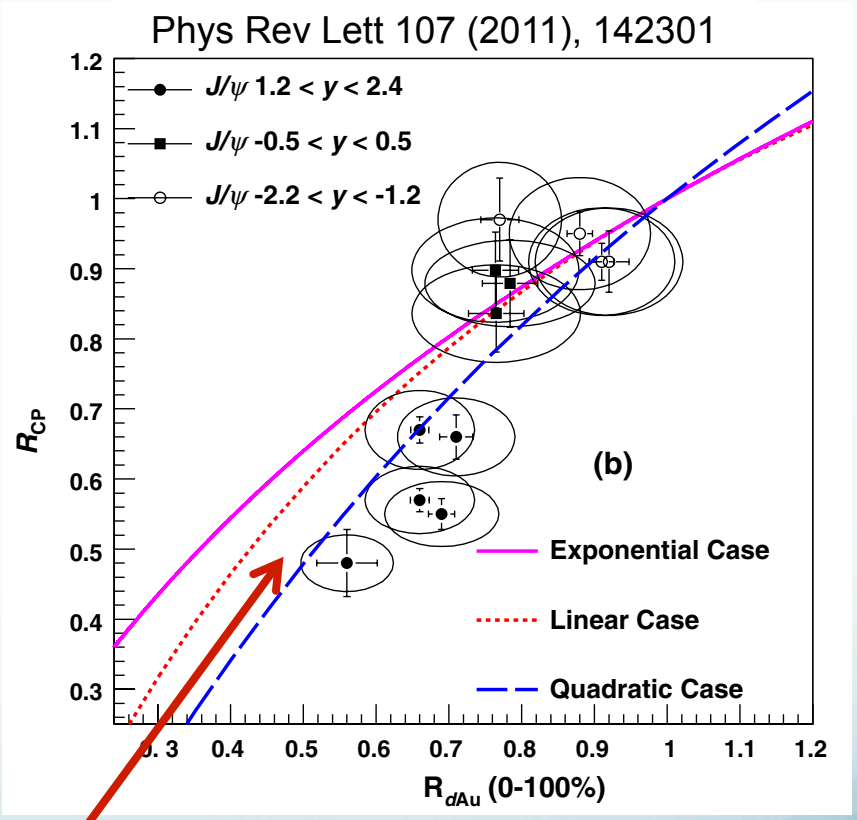
Published PHENIX Results

To remind people what has been published since last QM:

Phys Rev Lett 107 (2011), 172301

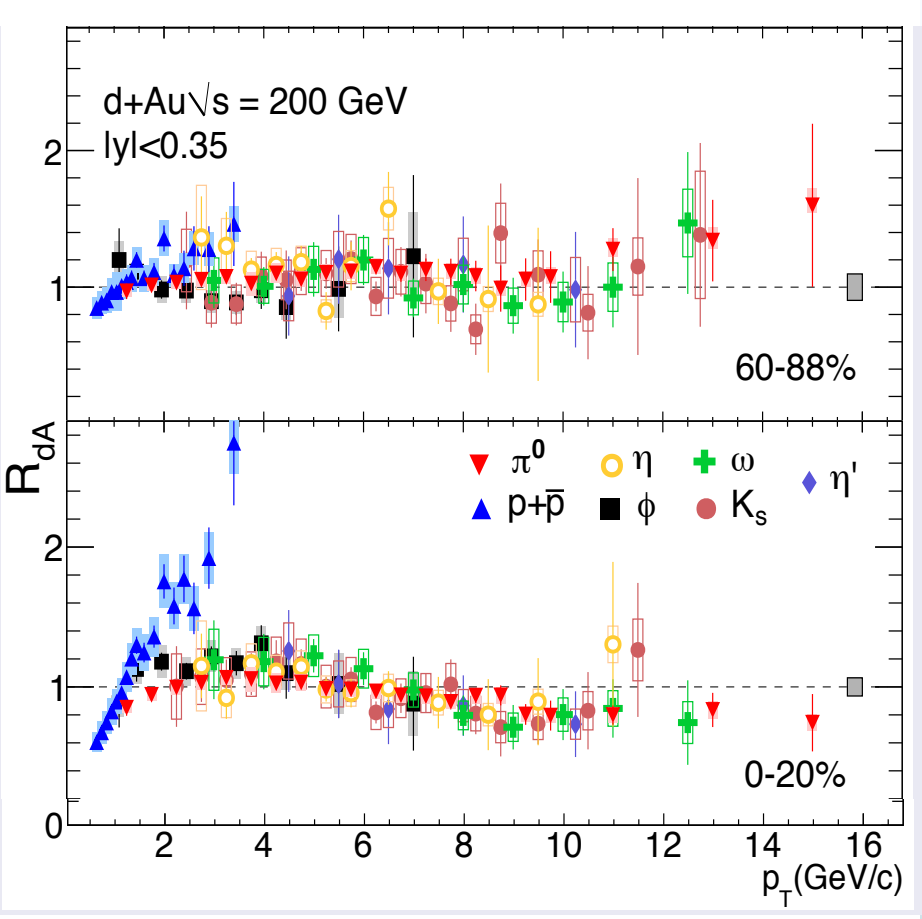


Phys Rev Lett 107 (2011), 142301



Strong suppression at low x_{Au} in central *d*+Au

R_{dA} of Identified Hadrons



Mesons follow similar trend w/ p_T in all centralities.

Cronin enhancement at moderate p_T?

Or nPDF moving through antishadowing region into EMC region?

Proton enhancement still not explained by Cronin or shadowing models.

- R. Hwa, et al. reproduced R_{CP} using recombination of shower + thermal(?) partons (nucl-th/0404066).

New Results

New and recent results that I'll discuss today include:

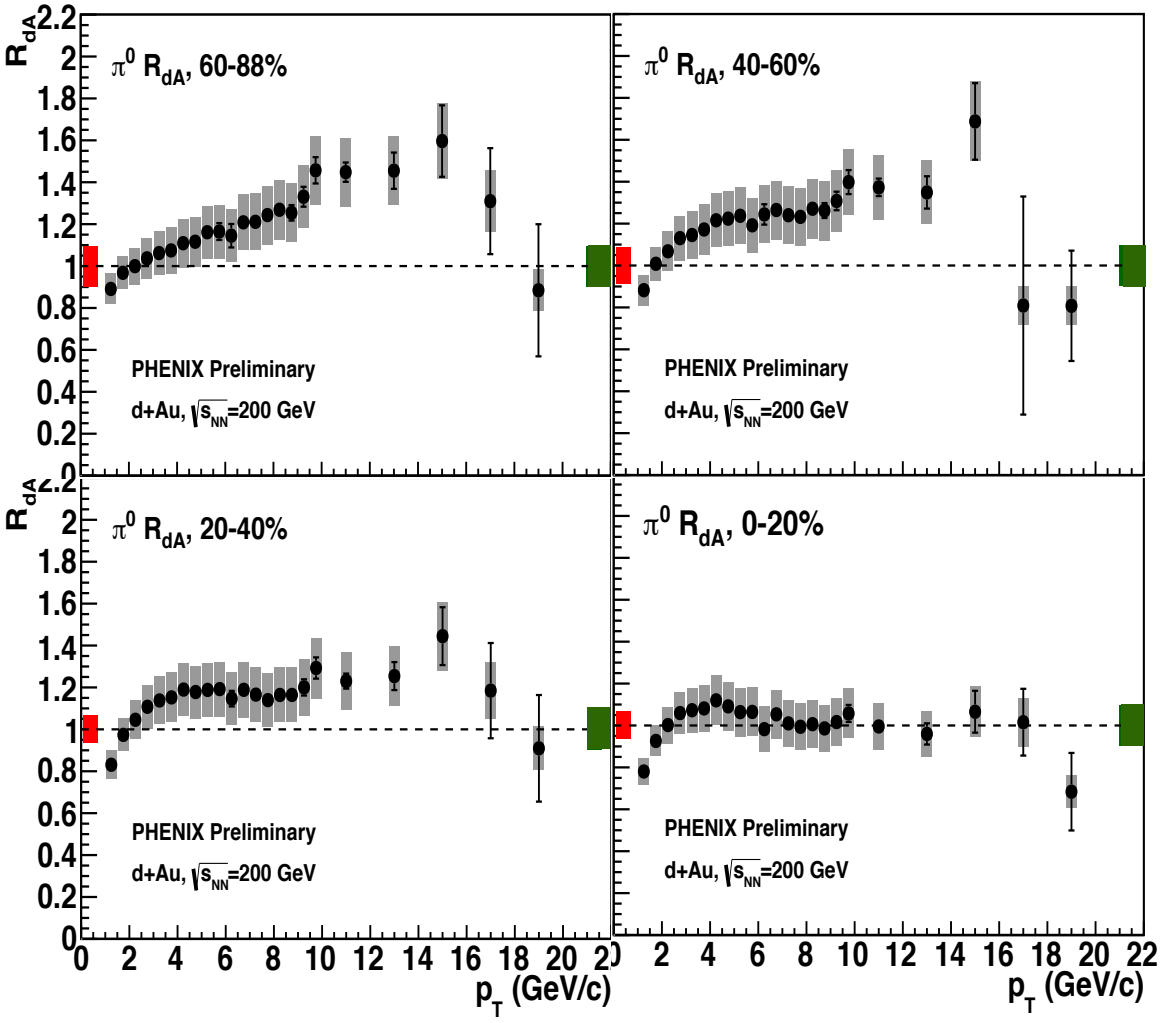
- π^0
- Reconstructed jets
- Electrons from heavy flavor decays
- J/ψ
- ψ'

PHENIX has our most comprehensive set of CNM measurements to date using Run 8 data.

But can we understand it all?

π^0 R_{dA} by centrality

New Result



New π^0 R_{dA} from Run 8!

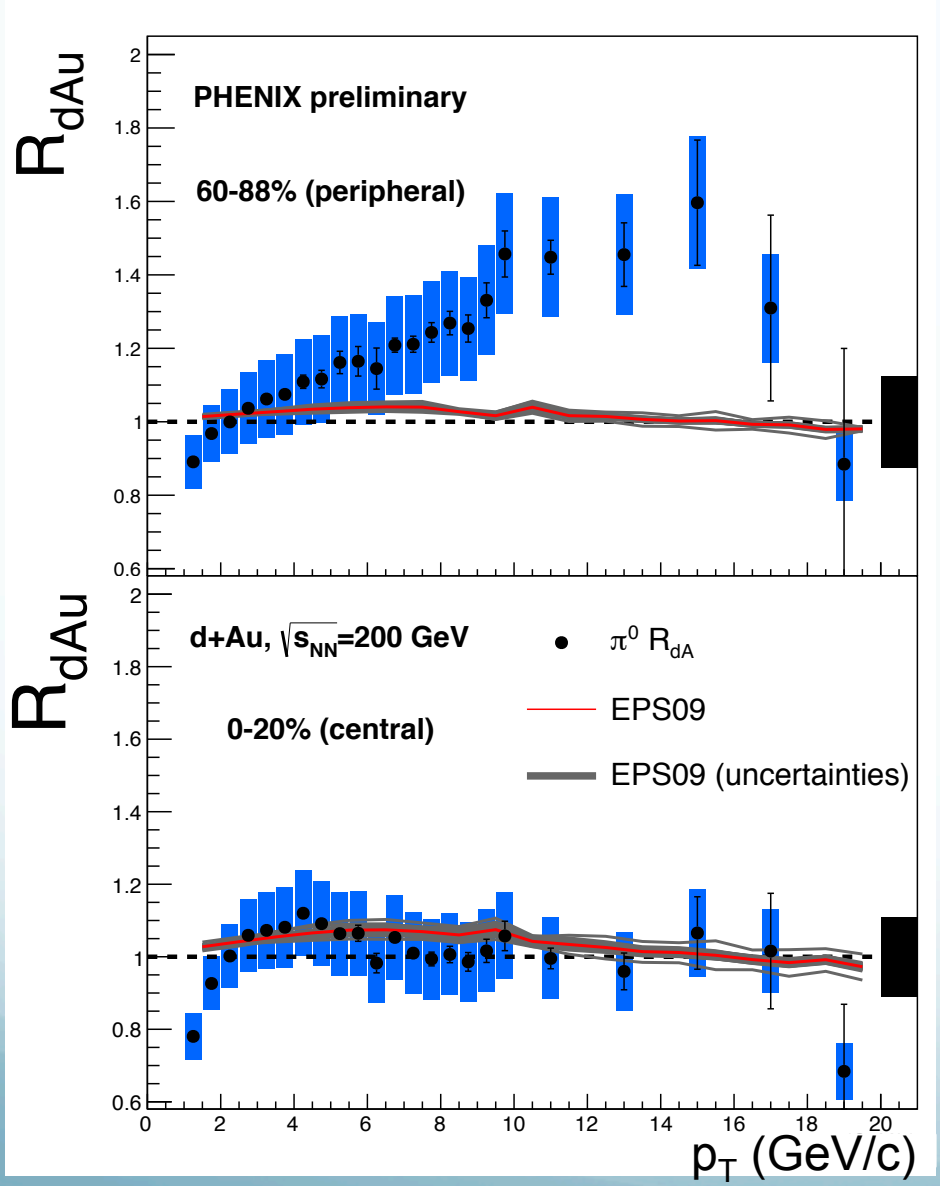
- Better statistics than Run 3
  → Extends p_T reach by 5 GeV/c
  → Better constraint for nPDFs

Peripheral is most enhanced

Central consistent with no modification at p_T > 2 GeV/c

How do we understand this? Competing nuclear effects?

π^0 R_{dA} by centrality



(Very basic) shadowing calculation uses EPS09 PDF modification* + Glauber MC + PYTHIA (x,Q^2) sampling for π^0.

Shadowing effects match reasonably well within the global scale uncertainties in central events (where modification is weak), but is not compatible with the p_T shape in peripheral.

See talk by Baldo Sahlmueller
Parallel Session 3D

*nPDF modification assumed to scale linearly with longitudinal nuclear thickness.

Reconstructed Jets

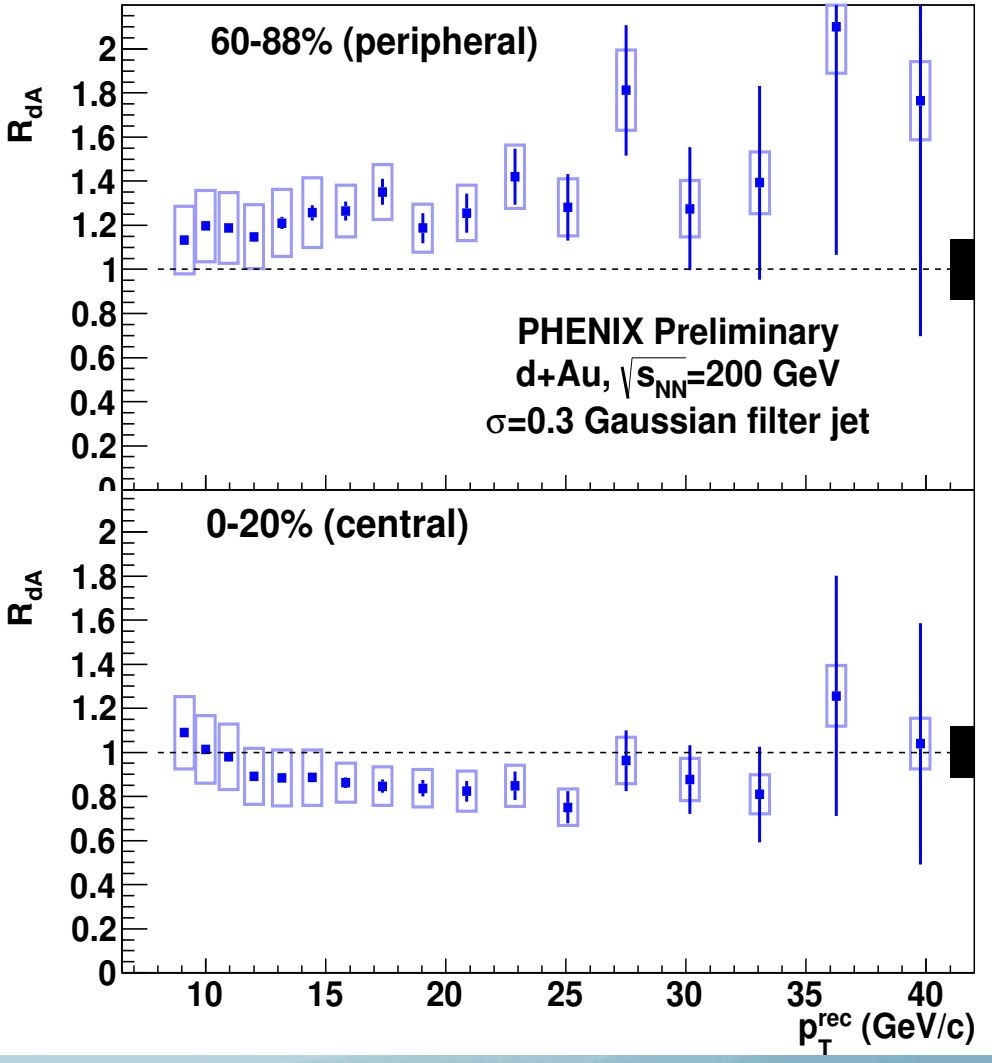
New Result

Jets reconstructed using Gaussian filter algorithm.

- Same algorithm used in Run 5 Cu+Cu and p+p analyses

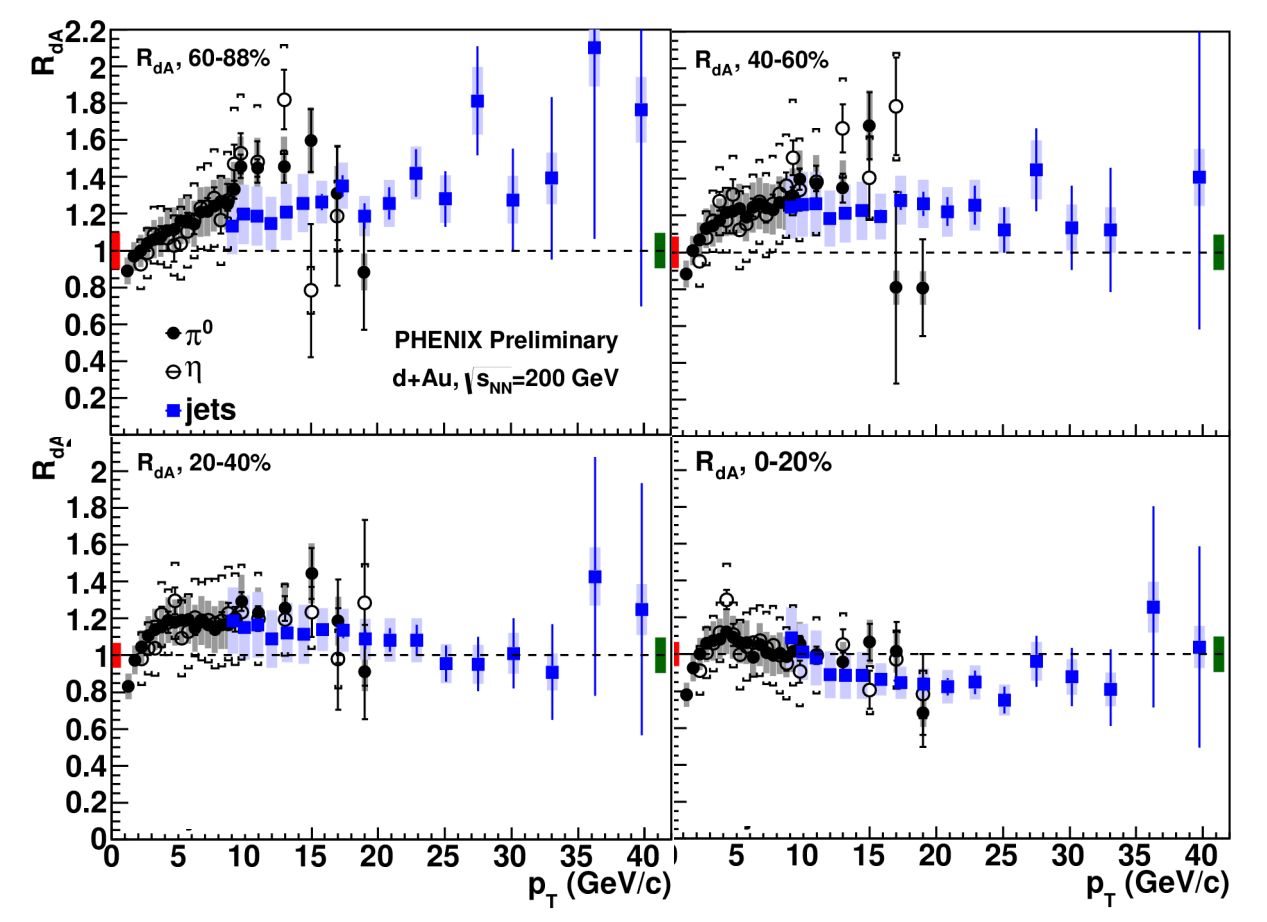
Higher p_T reach than π^0s

Enhancement in peripheral, suppression in central, sound familiar?



Comparison to π^0 R_{dA}

π^0 and jets of same p_T sample slightly different parton scales, but let's overlay them anyways…



Good agreement within uncertainties, and given the difference in observables.

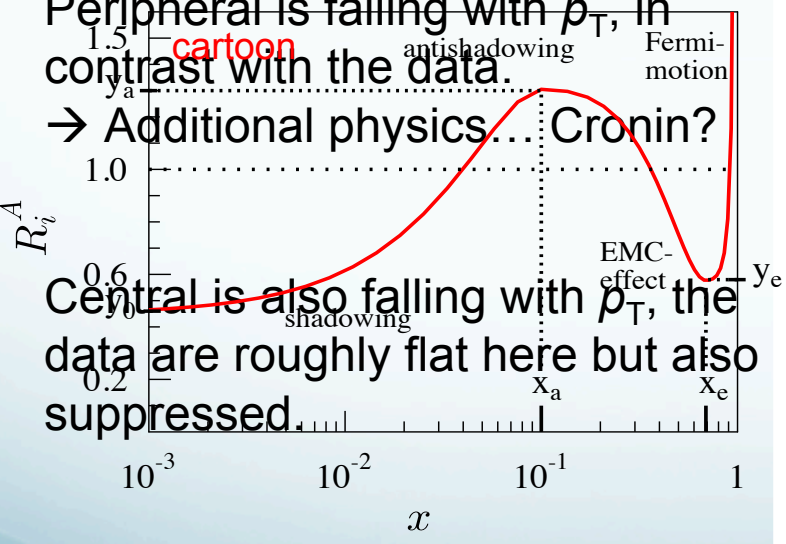
Comparison to shadowing calculation

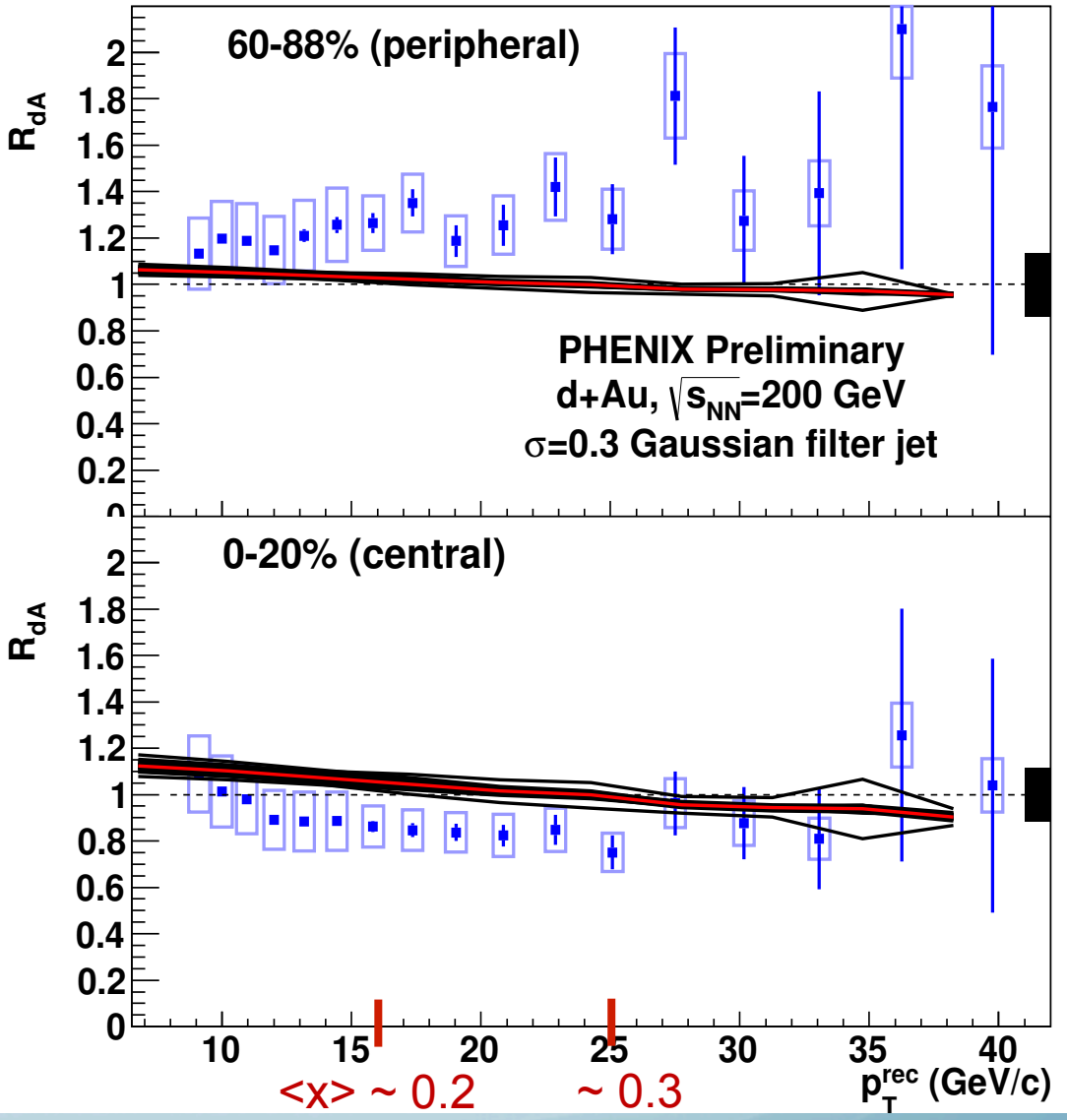
Use the same shadowing (EPS09) + Glauber MC model as before…

Moving from antishadowing region in *x* of the Au nucleus → EMC effect.

Peripheral is falling with p_T, in contrast with the data.
→ Additional physics… Cronin?

Central is also falling with p_T, the data are roughly flat here but also suppressed.





See Plenary IIA talk by Mike McCumber and poster by Dennis Perepelitsa

Heavy Flavor Electrons

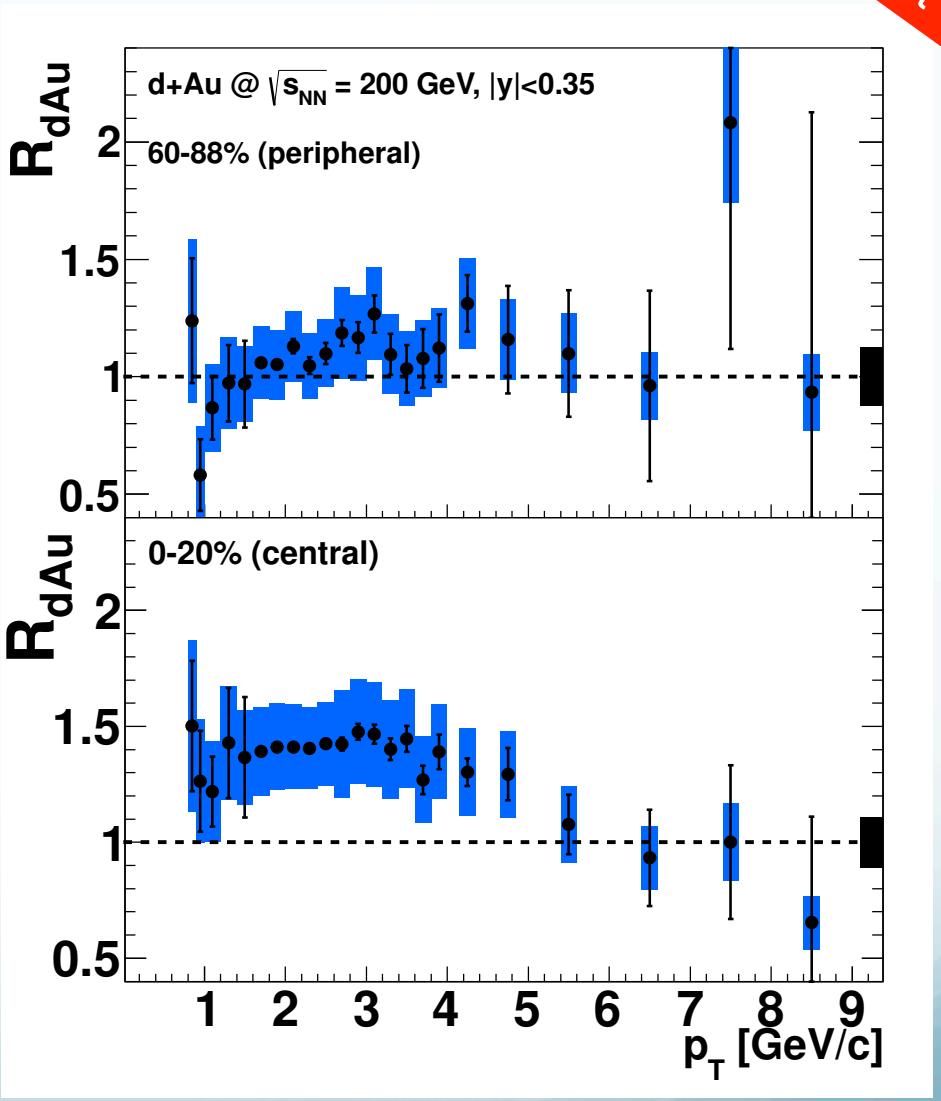
New Result

Single electrons from heavy flavor semi-leptonic decays

Enhancement at intermediate p_T
→ Cronin-like k_T scattering?

No evidence of suppression
→ Au+Au effect entirely HNM?

Detector configuration prevented measurement below p_T~0.8 GeV/c



arXiv:1208.1293, submitted to PRL

Comparison to EPS09 calculation

Single electrons from heavy flavor semi-leptonic decays

Enhancement at intermediate p_T
→ Cronin-like k_T scattering?

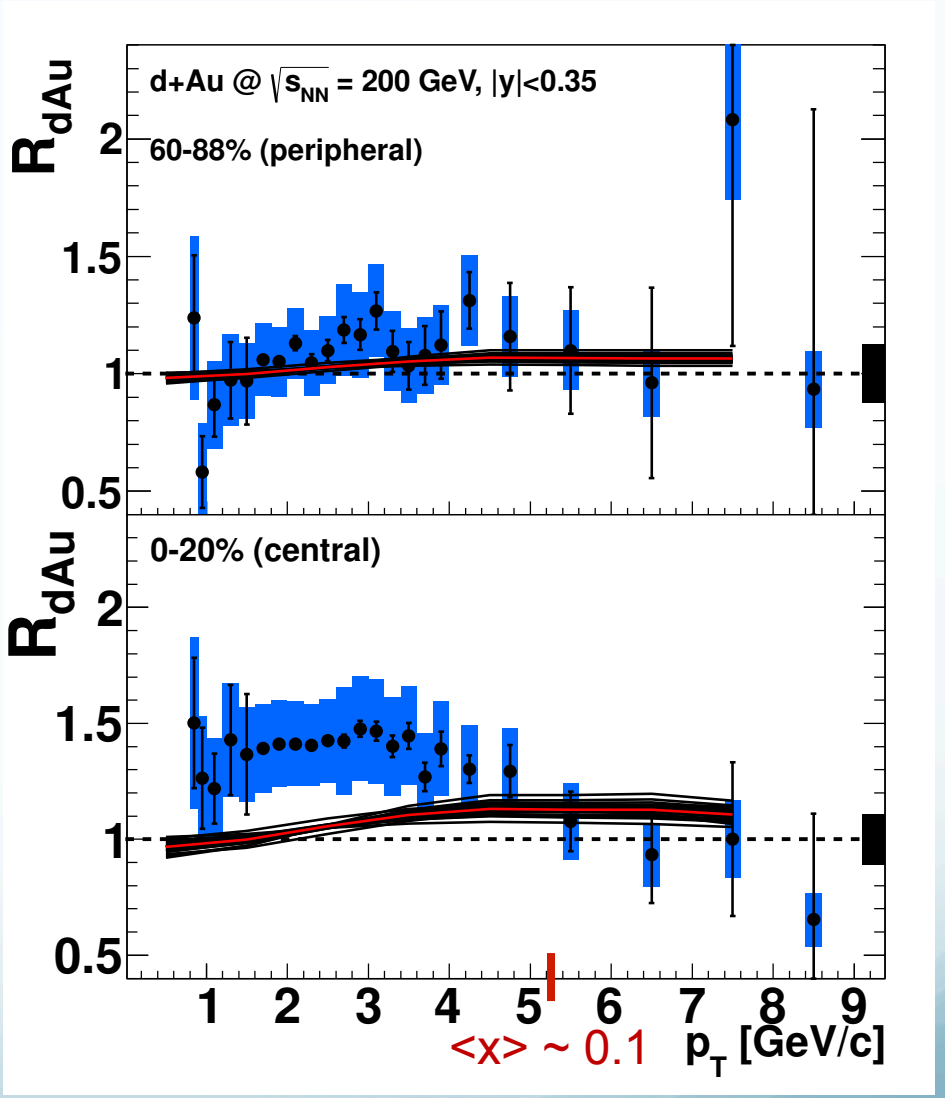
No evidence of suppression
→ Au+Au effect entirely HNM?

Detector configuration prevented measurement below p_T~0.8 GeV/c

Shadowing-only calculation is able to reproduce the peripheral modification, but not central (not even qualitatively).

→ Opposite of π^0 case
→ Need additional physics

See poster by Matt Durham

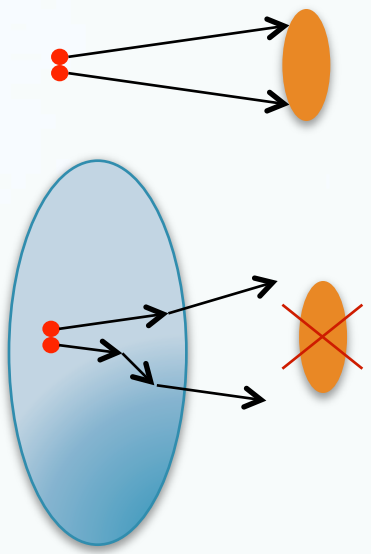


arXiv:1208.1293, submitted to PRL

Charmonia in CNM

Still have shadowing, Cronin enhancement.

Additional effect due to size of *c*-*c*bar bound state: break up due to interactions in nucleus.



Included as σ_{br}, which decreases with sqrt(s_{NN}). Behavior with rapidity/p_T not clear.

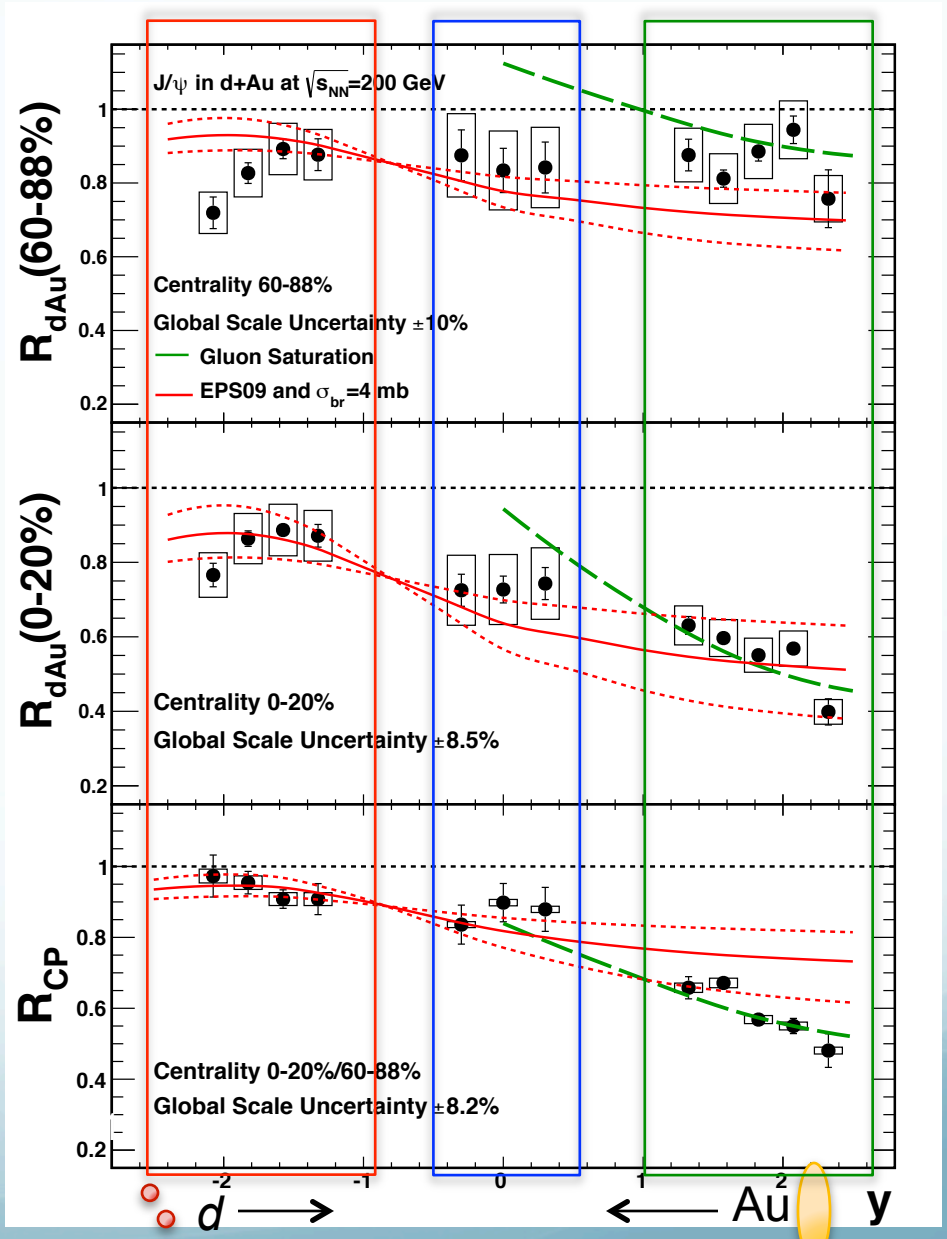
J/ψ in CNM

Phys. Rev. Lett. 107 (2011) 142301

J/ψ are suppressed at all rapidities, in all centralities.

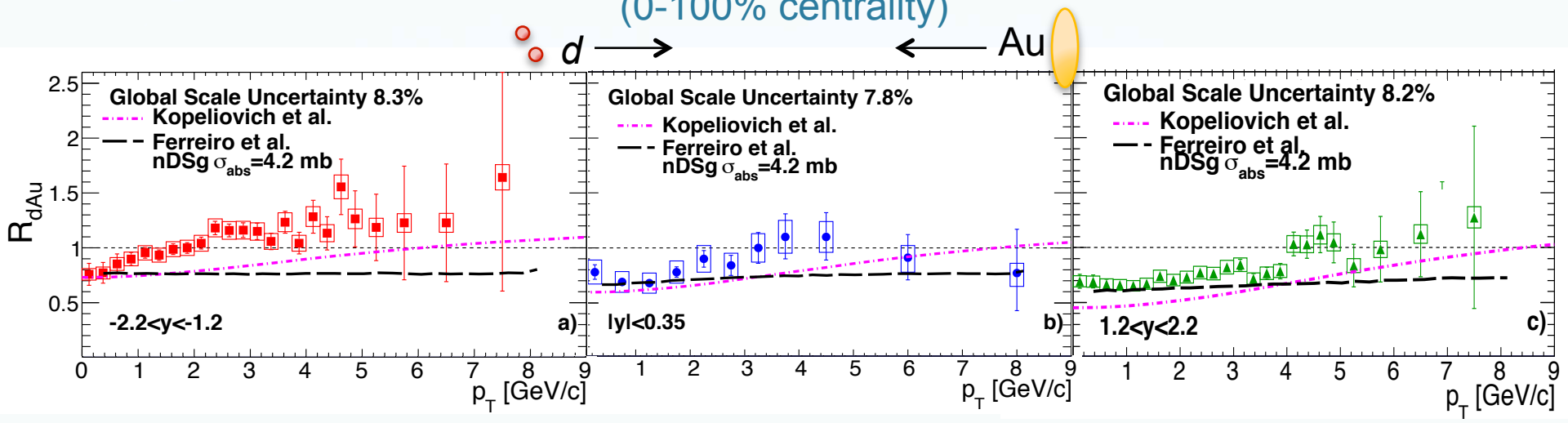
Model using shadowing (EPS09) + σ_{br}

Qualitatively matches what we see, but cannot simultaneously capture the rapidity and centrality dependence.



J/ψ vs. p_T

(0-100% centrality)



R_{dAu} rises out to p_T~5 GeV/c at all rapidities.

Largest disagreement with models is at backward rapidity.

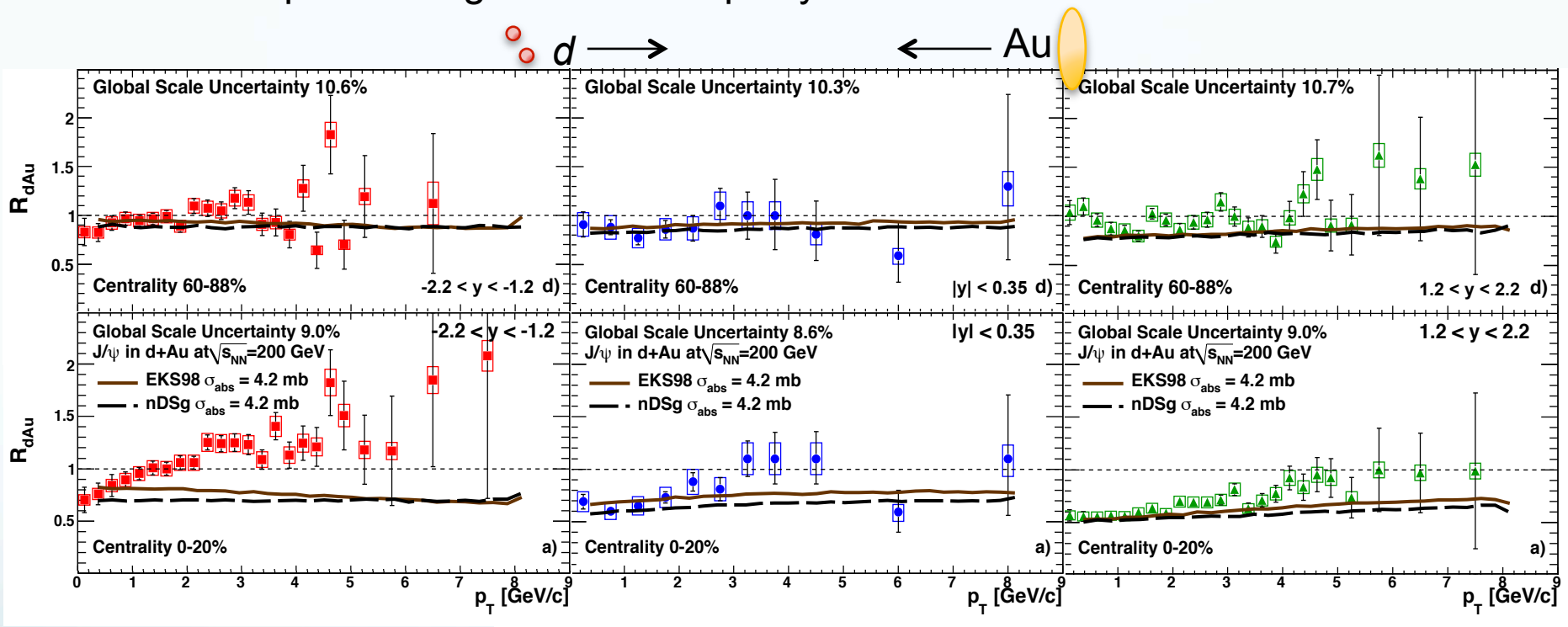
Shadowing + σ_{br} model (no Cronin) does not match the qualitative trend.

Model by Kopeliovich et al. includes Cronin and σ_{br} prediction, qualitatively matches the p_T shape.

arXiv:1204.0777, submitted to Phys Rev C

J/ψ vs. p_T
(peripheral and central)

Weak modification in peripheral; shadowing reproduces fairly well, except to strong at forward rapidity



Stronger modification in central; shadowing alone cannot reproduce the trend

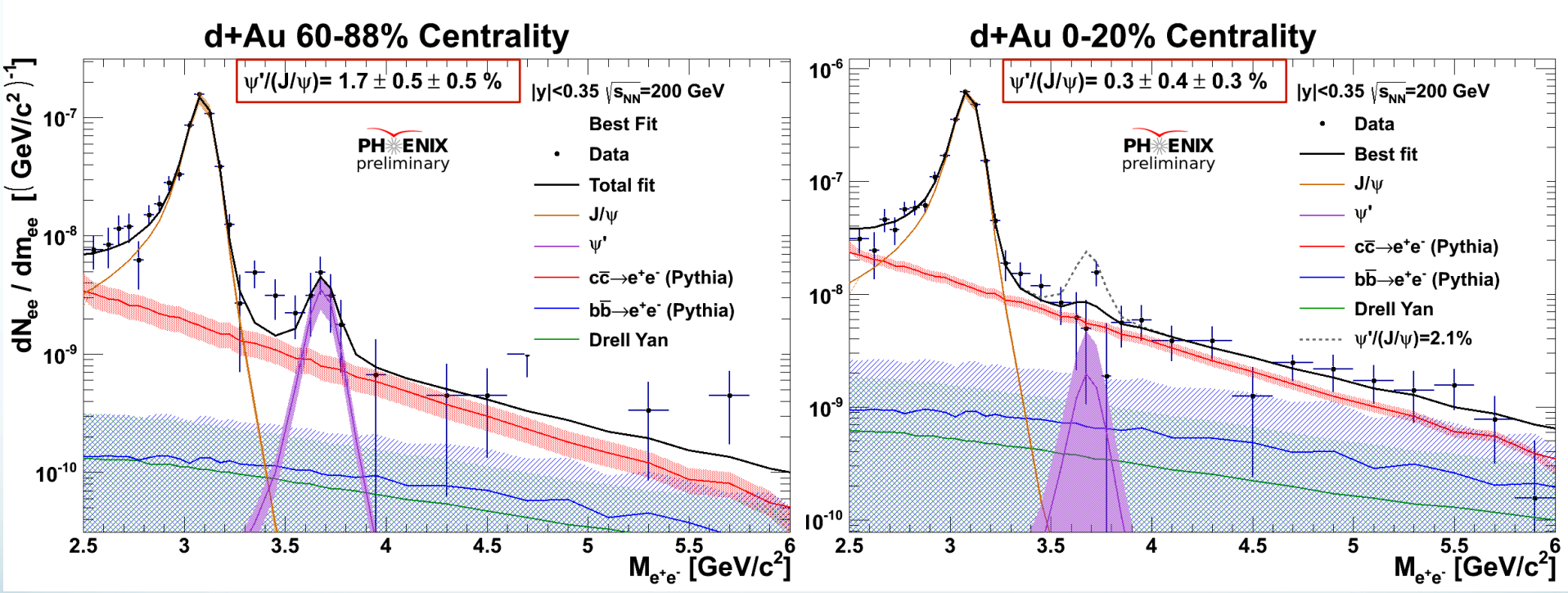
Backward rapidity: high p_T → EMC effect suppression
Need Cronin-like scattering or some other physics!

See Parallel 1D talk by Darren McGlinchey

ψ' at midrapidity

New Result

$\psi'/(J/\psi)$ in p+p = 2.1 ± 0.5%



Consistent with zero in most central collisions!

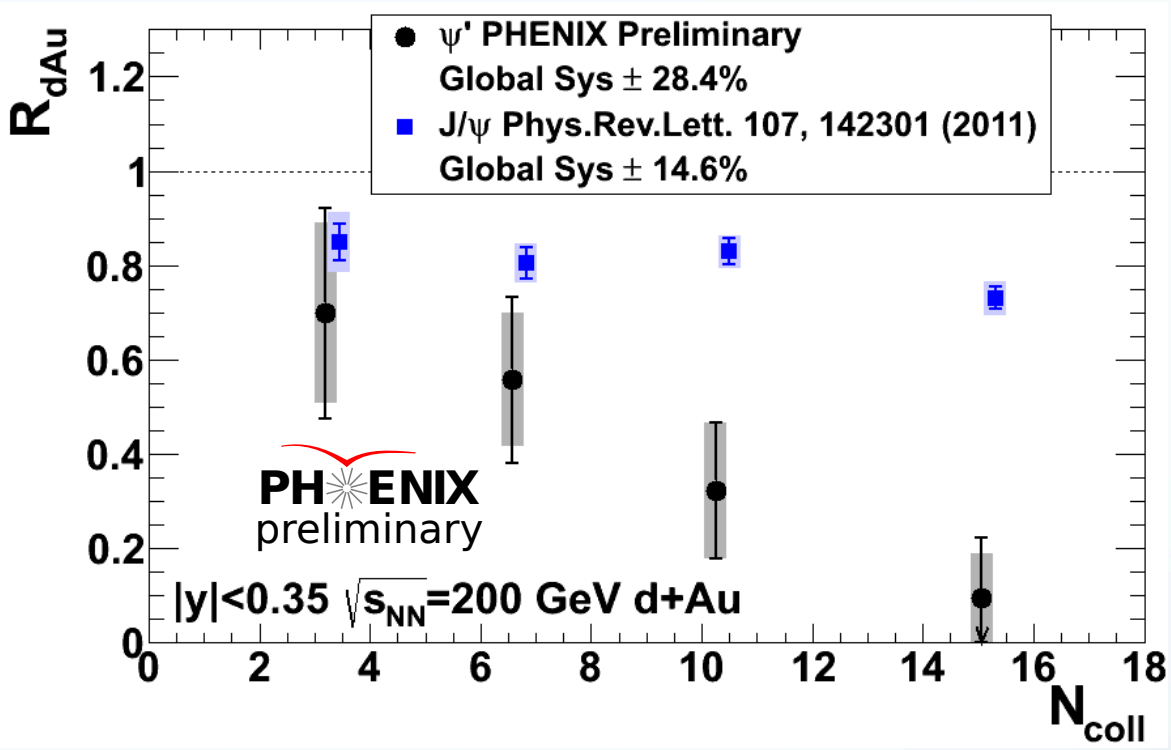
ψ' at midrapidity

New Result

Consistent with zero in most central bin

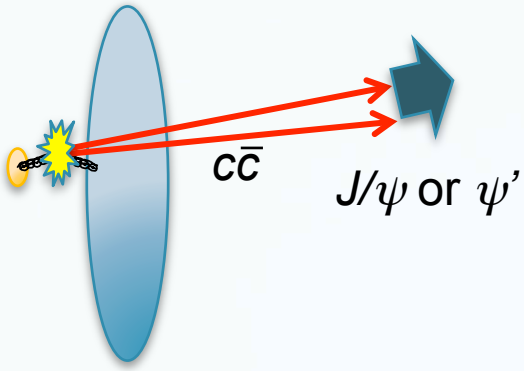
Completely different from J/ψ case

- J/ψ also includes ψ' feed-down.



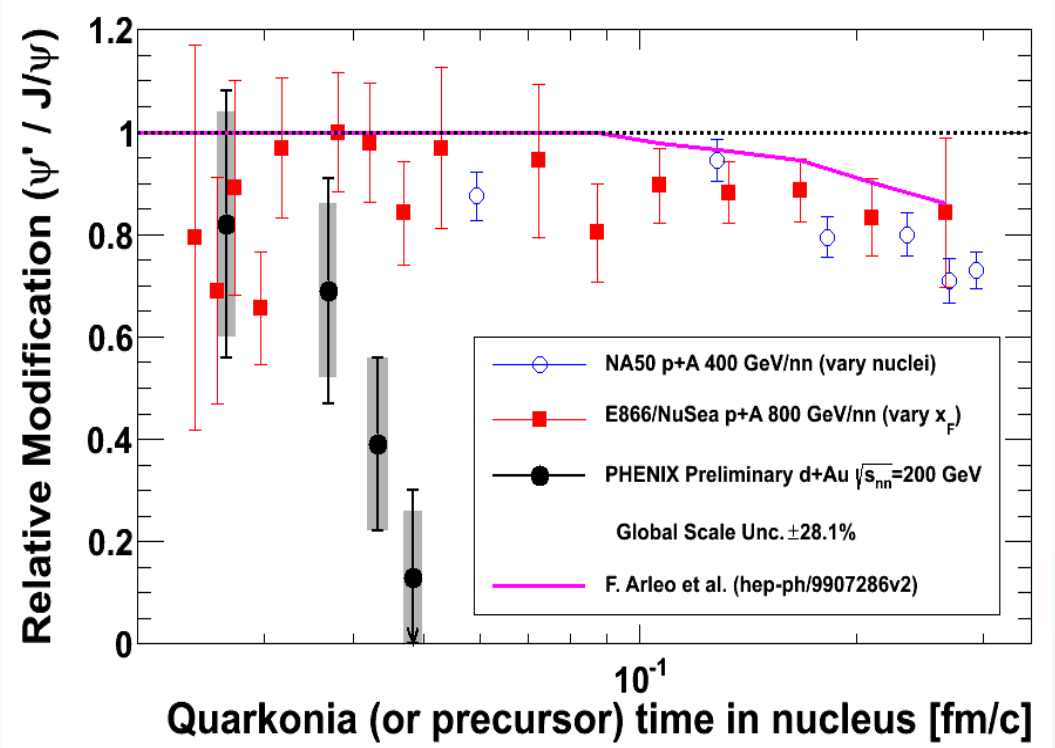
Shadowing/Cronin should be the same…
→ Different break-up cross sections?

ψ' has a radius ~twice the size of J/ψ, so isn't this what we expect?



ψ' / J/ψ ratio should be unity when the time in nucleus < formation time.

Curve is a model calculation based on NA50 and E866 data.

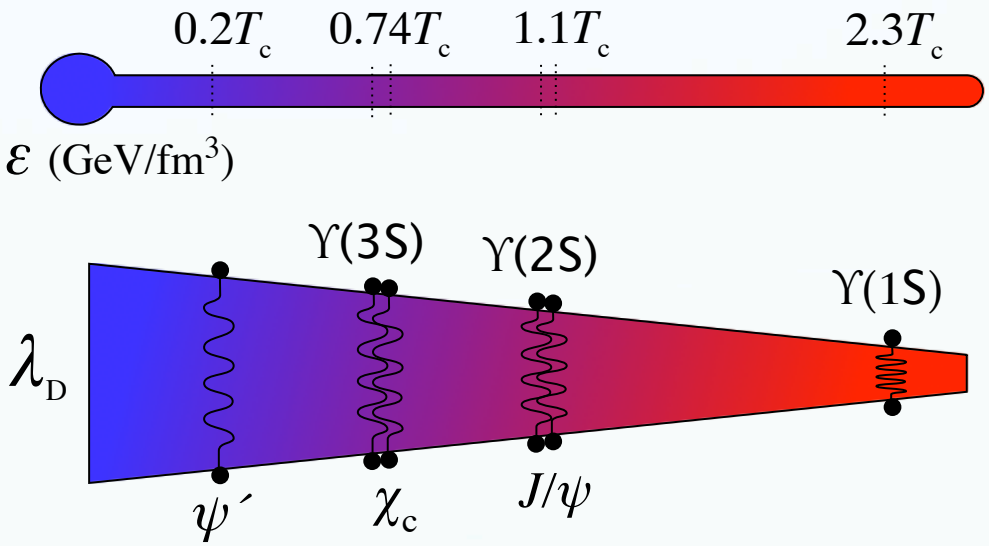


New PHENIX data is completely at odds with this picture

See Parallel 1D talk by Darren McGlinchey

A+A→QGP Implications

Impossible to use charmonia (even bottomonia?) as a QGP thermometer without calibrating the CNM suppression first!



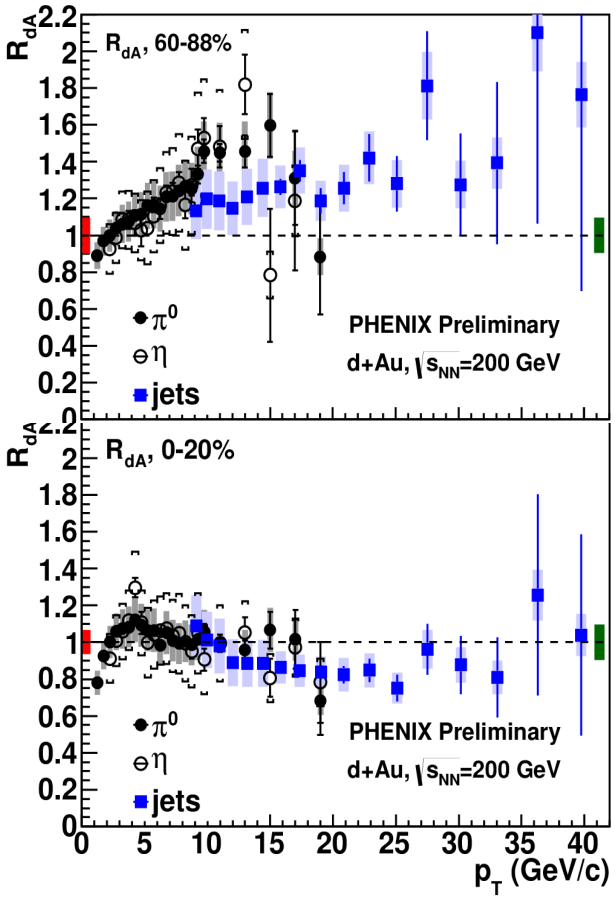
We are going to need:

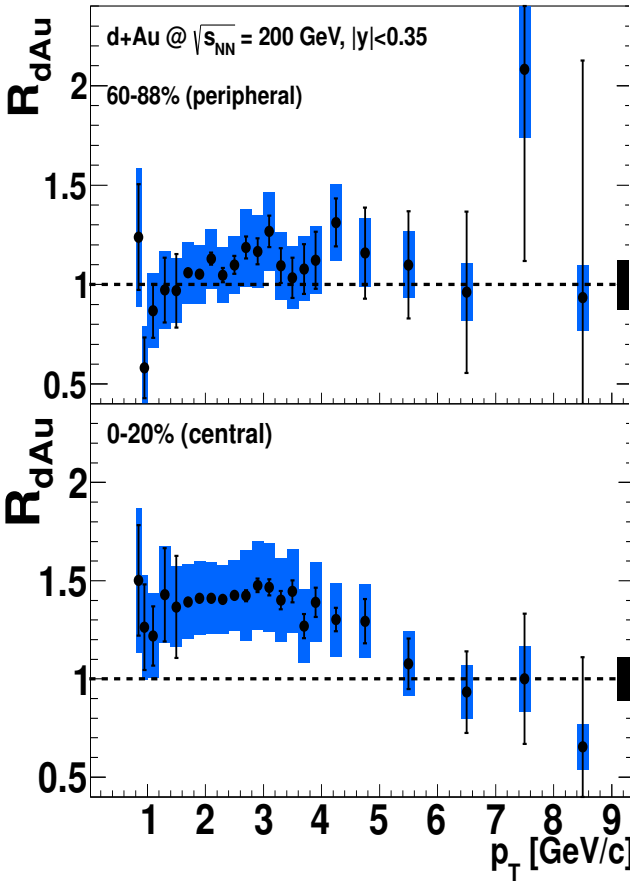
1. **Precision charmonia and upsilon measurements in *p+A* at the LHC and *d+A* with sPHENIX at RHIC.**
2. **Precision models to extrapolate CNM measurements to *A+A*.**

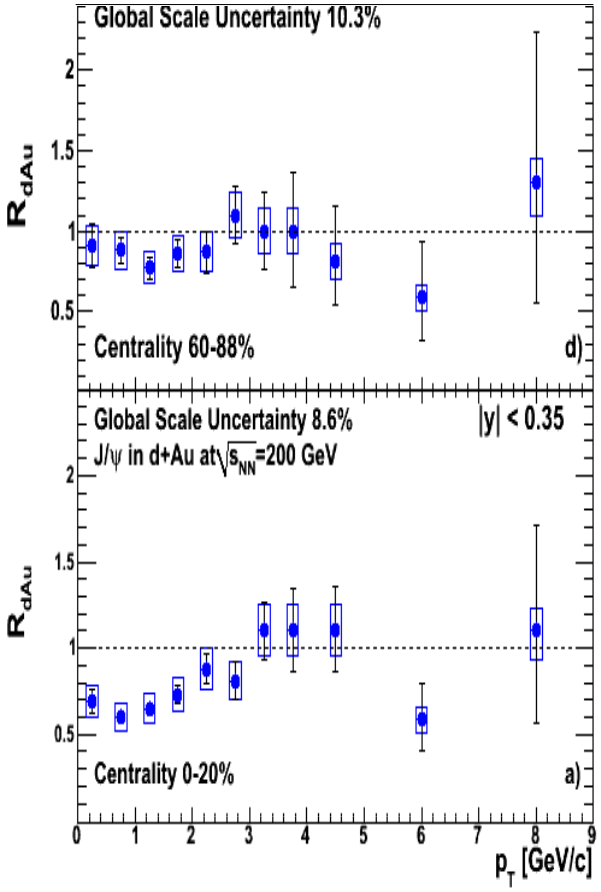
Summary

PHENIX has a comprehensive set of *d*+Au measurements available.
Plenty for theorists to chew on! Many interesting effects!

π^0 jets Electrons from HF J/ψ

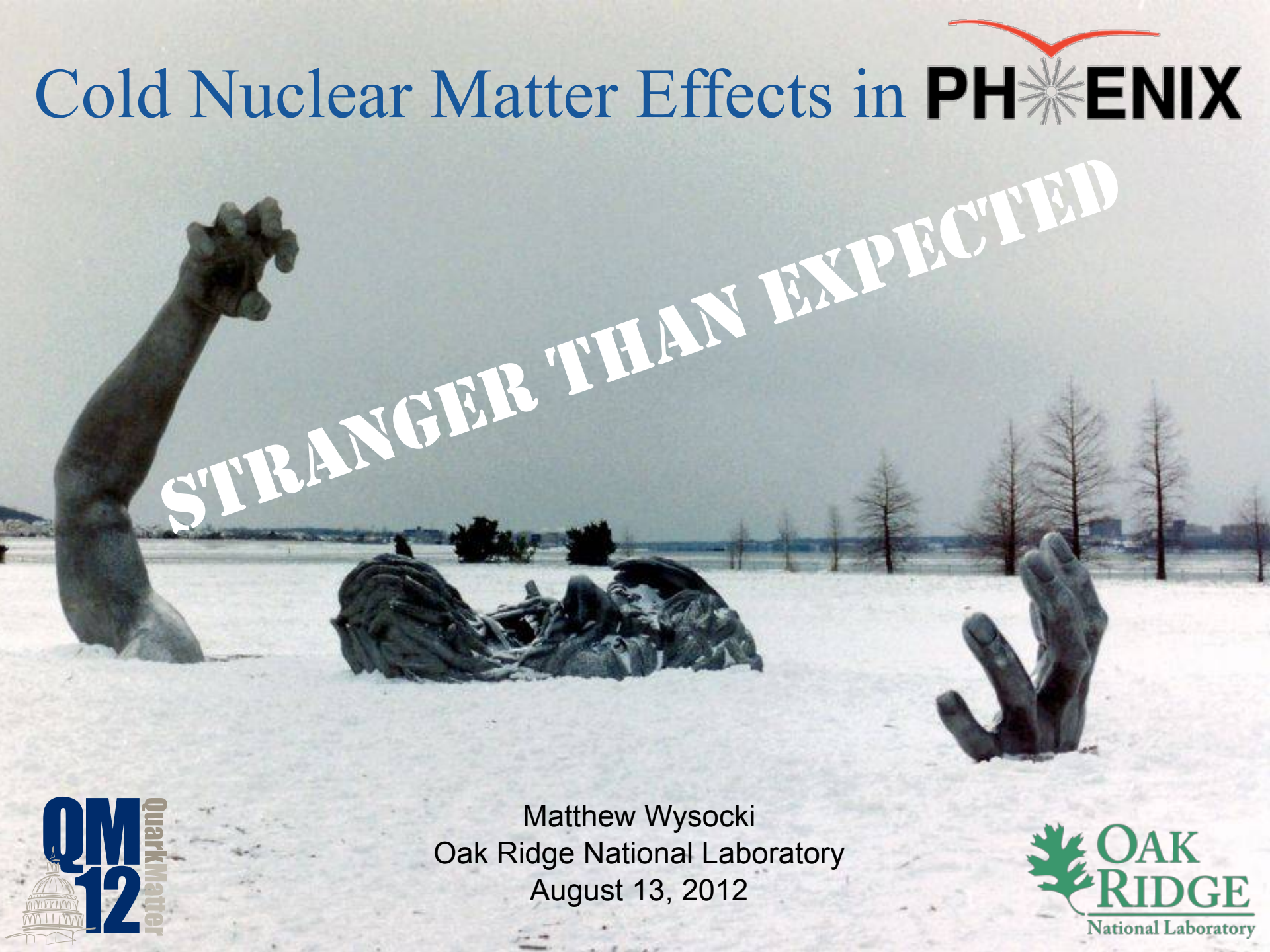






ψ' is strongly suppressed in central collisions, in contrast with J/ψ.

Cold Nuclear Matter Effects in PHENIX



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Backup

(in)conclusions

- Some results are explained reasonably well by shadowing/Cronin enhancement, but many are not.
  - Proton enhancement not explained by traditional Cronin models.

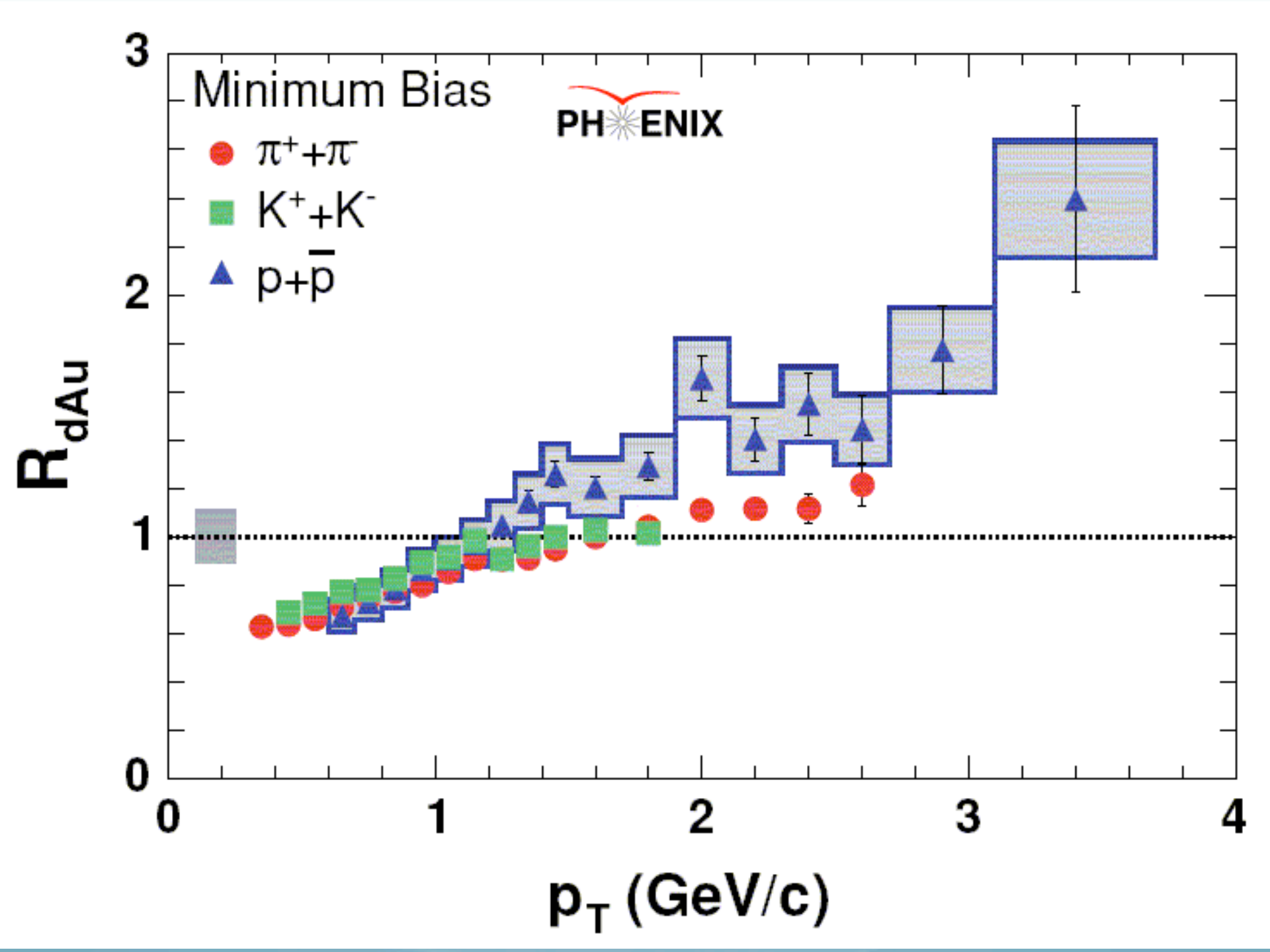
- In particular: R_{dA} vs. p_T for peripheral π^0 and jets, and central HF electrons and J/ψ are not reproduced by the current models.

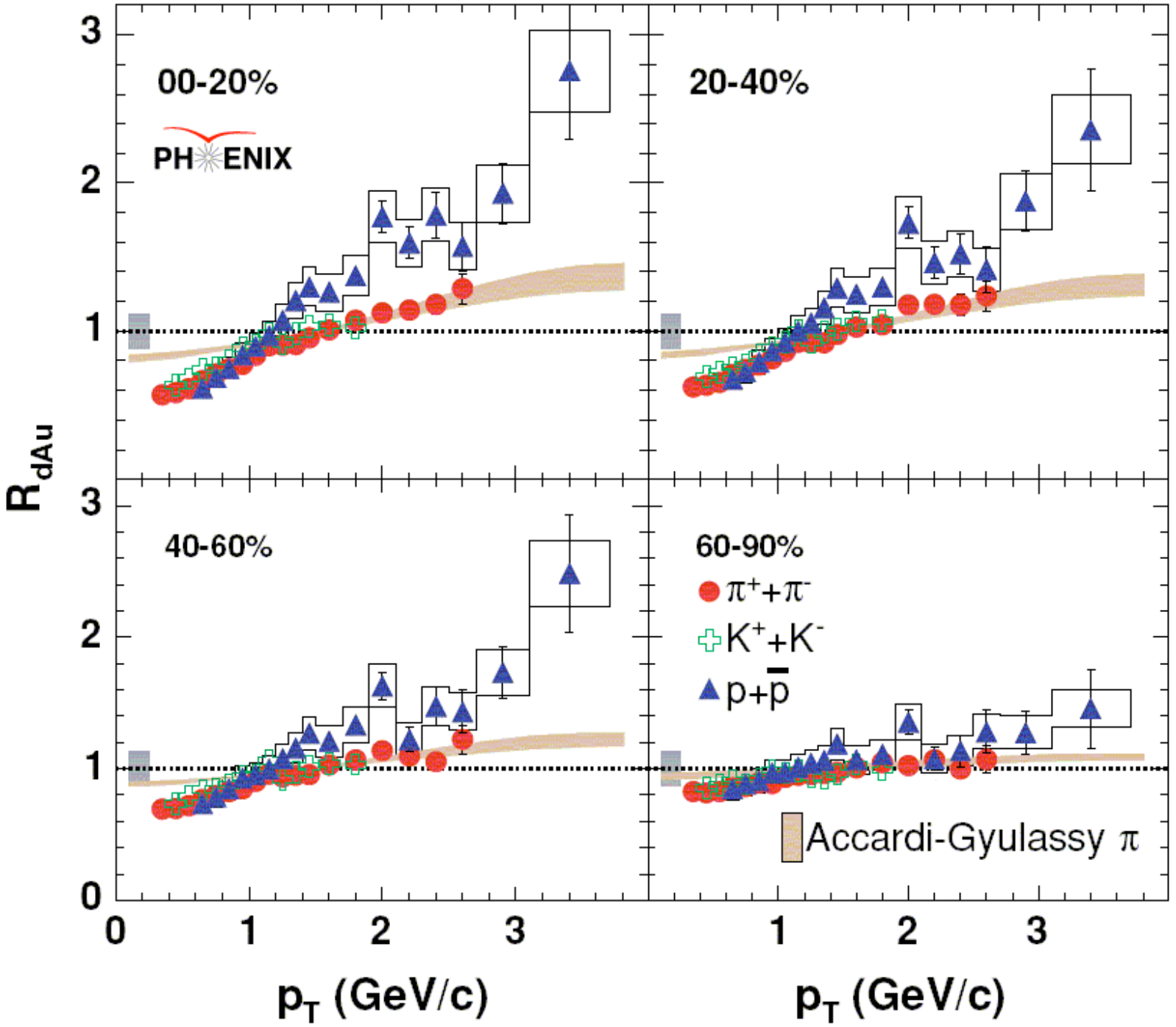
- ψ' suppression not understood within current charmonia picture.
  - LHC *p+A* measurements of heavy quarkonia will be a necessity

- Centrality/geometric dependence of modification not understood.

Still a lot of mystery in CNM effects at RHIC!

MPC-EX and sPHENIX upgrades will provide even better constraints down the road, but the current data already presents a *strong challenge to theoretical models.*


Minimum Bias
PHENIX
π⁺+π⁻
K⁺+K⁻
p+p̄
R_dAu
p_T (GeV/c)
0
1
2
3
4


00-20%
PHENIX
20-40%
40-60%
60-90%
π⁺+π⁻
K⁺+K⁻
p+p̄
Accardi-Gyulassy π
R_dAu
p_T (GeV/c)
p_T (GeV/c)
0
1
2
3

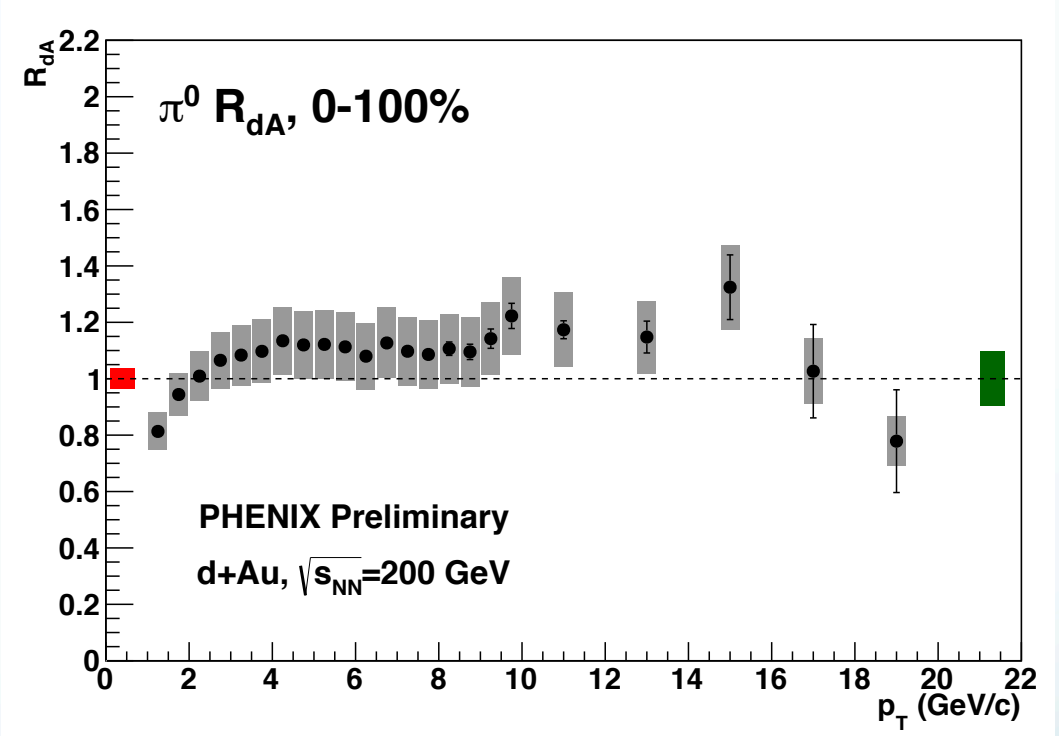
π^0 R_{dA}

New Result

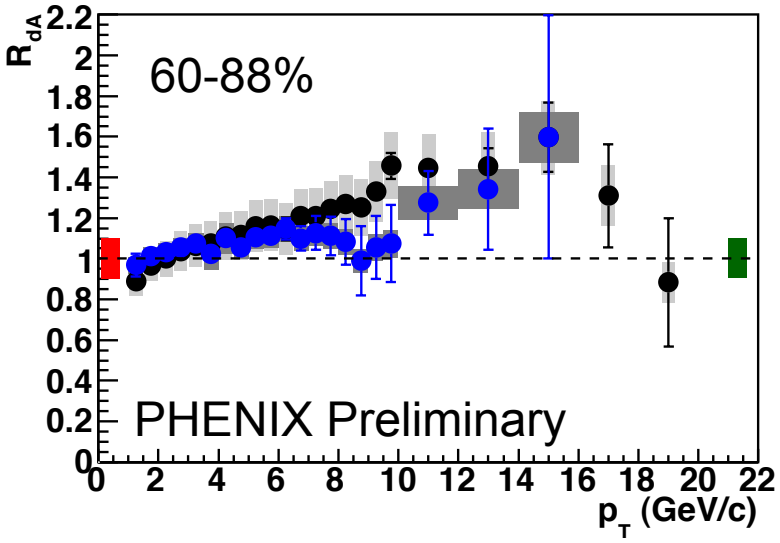
New π^0 R_{dA} from Run 8!

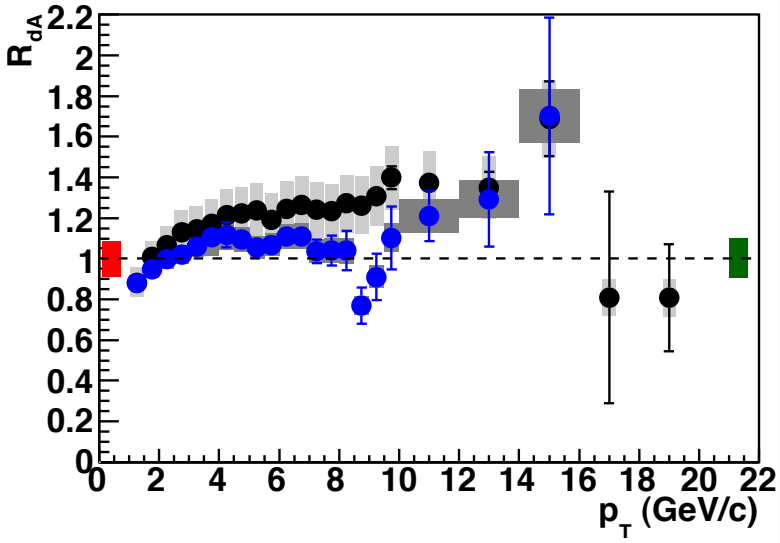
- Better statistics than Run 3
  → Extends p_T reach by 5 GeV/c
- Better constraint for nPDFs
- Larger correlated systematics b/c p+p is from different year.

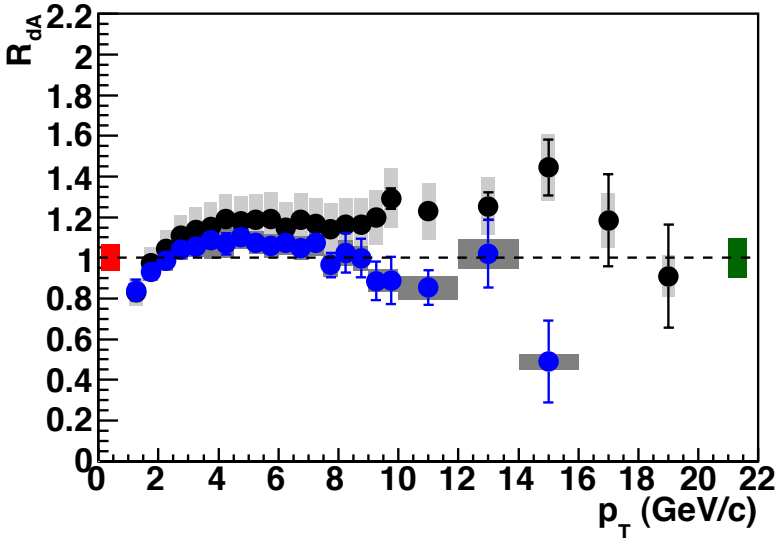
Some enhancement p_T > 2 GeV/c
- Anti-shadowing?
- Cronin initial-state scattering?

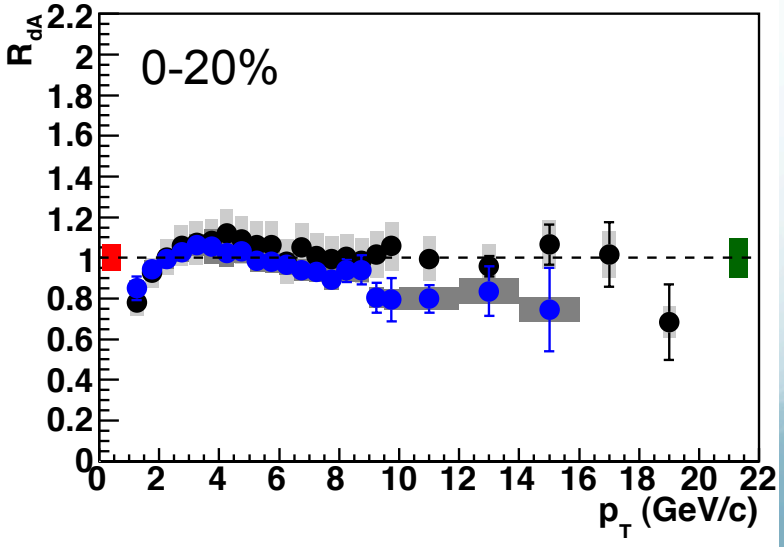


See talk by Baldo Sahlmueller
Parallel Session 3D

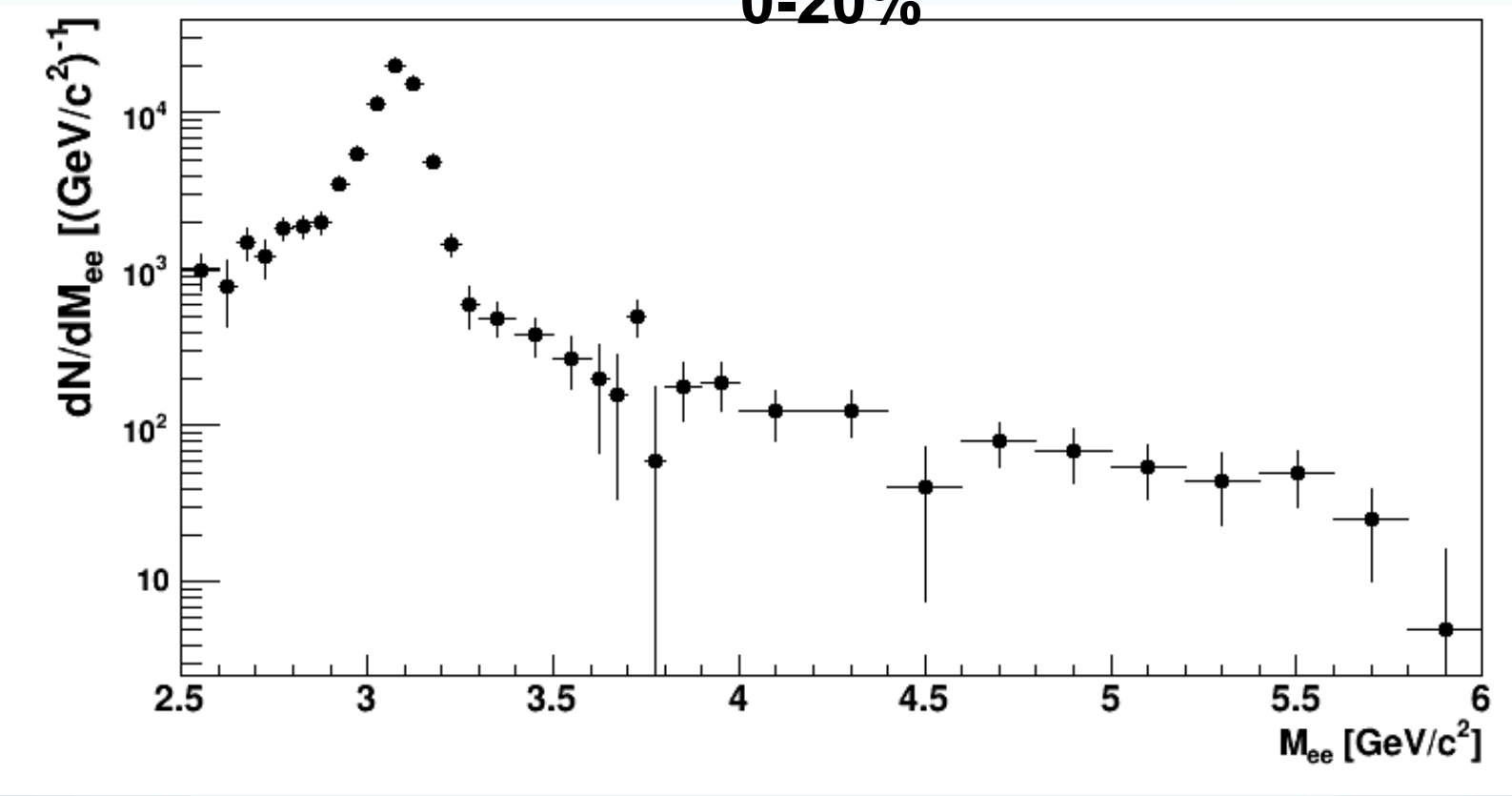

60-88%
PHENIX Preliminary
R_{dA}
p_T (GeV/c)


R_{dA}
p_T (GeV/c)

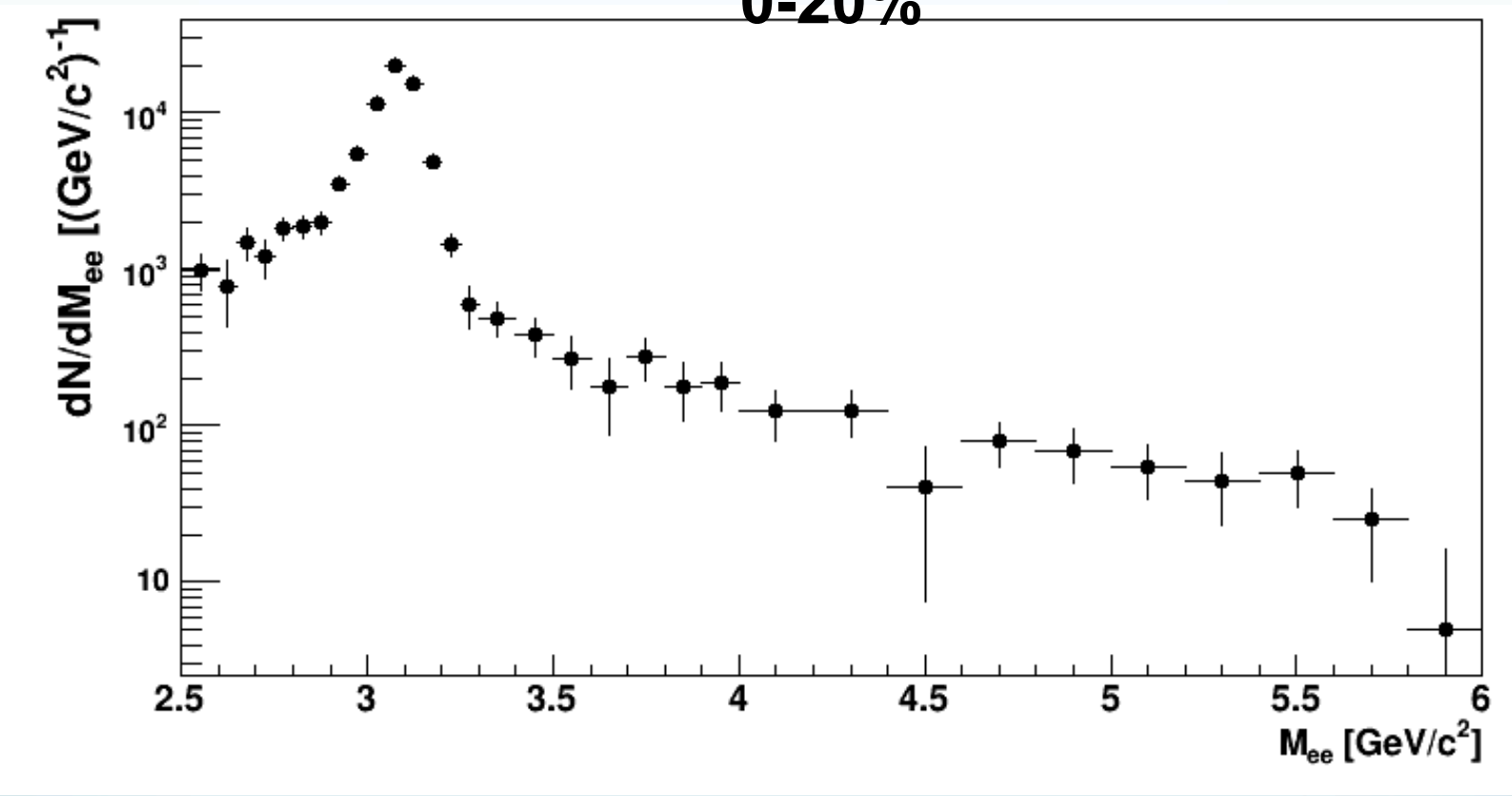

R_{dA}
p_T (GeV/c)


0-20%
R_{dA}
p_T (GeV/c)

Mass Plot



Mass Plot



Summary

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π^0 jets Electrons from HF J/ψ